Soft Upper-limb Rehabilitation Exoskeleton
Investigating Discrimination in Stroke Rehabilitation

A Thesis Prospectus
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

When the blood supply in the brain is cut off by a blockage in the artery, causing an ischemic stroke, patients are at risk of death and long term cognitive or physical disabilities. This project focuses on the physical ailments, which can cause difficulty walking, controlling upper limbs, and may prevent sufferers from having the ability to live unassisted (Dobkin, 2005).

If a stroke is caught and treated in time, patients undergo physical rehabilitation in the following months, with the goal of regaining mobility. Many exercises have been widely adopted due to their effectiveness, but studies still show that, "ten years after, 46% of the population had some level of disability" (Carmo et al., 2015, p.410). Almost half of all stroke survivors suffer from long term disabilities that decrease their quality of life and can negatively impact mental health. The chance of regaining total motor function is not the same for all sexes, races, and ethnicities. White males see the highest success rates of rehabilitation compared to other demographics, most notably females and African Americans. In the Framingham Study, which evaluated gendered differences in post-stroke disability, it was found that though, "the severity of neurological deficits was similar for both genders, the women were functionally more disabled" (Kelly-Hayes, 2003). A similar study on racial differences found, "Physical impairment was significantly more severe in black than in white patients at admission, and although physical impairment improved, it remained significantly worse in blacks" (Horner, 1991, p. 1)

Significant research has shown that African American males are at a higher risk of stroke at a young age. While this research will not look into the causes of higher stroke prevalence, it will investigate why this demographic has not received the after care and research attention that

should be expected for an at-risk population. A study comparing stroke prevalence for different races found that black males are at, “approximately a 3-times-higher risk of a first stroke at age 45, but a diminishing racial disparity at older ages,” (Howard, et al., 2016) when compared to white males.

Allowing this disparity to persist reinforces socio-economic classes and archaic notions of white male superiority. To rectify this issue, the cause must be identified, and additional research must be conducted to develop a plan that provides the same quality of care to all racial and ethnic groups and sexes. My technical project will design an upper limb wearable exoskeleton, composed of textiles, to assist in stroke rehabilitation of the elbow and hand. My STS project will research the cause of lower stroke recovery rates for females and African Americans.

Technical Topic

Two of the widely adopted exercises used in stroke rehabilitation are flexion and extension of the elbow, and clenching and unclenching of the fists. The key to the success of these therapies is repetition, which can often be impeded by therapist fatigue, time constraints, and cost. When attempting to overcome these limitations using rehabilitation robots, one necessary aspect is the “ability to impose high intensity, measurable and repeatable motions to humans” (O’Neill, et al., 2020, p. 1).

Prior research has helped to develop upper limb exoskeletons that can perform motions for the user. Some of the faults with existing designs include price, weight, portability, and comfort for the user. Overcoming these setbacks would give more people access to on demand, at home, upper limb rehabilitation.

Various actuators, or motion generators, have been developed and tested for implementation in upper limb exoskeletons. The use of a motor and Bowden Cable gives our design several advantages when compared to pneumatic actuators or hard frame exoskeletons. The key challenges of soft exoskeletons are "weight, safety, portability, softness, comfort," as stated by Perez (2021). The cable connects to a wrist cuff, which eliminates the need for any stiff components of the arm. By using wrist cuffs, we lower the apparatus weight, improve comfort, and allow for adjustability from different arm lengths and widths. The adjustability will allow for widespread use for a variety of body types.

Another advancement our design makes on previous research designs is the addition of a second degree of freedom. Using fused gloves, a second small motor, and a thinner cable, the fingers will be pulled into a fist when the arm flexes. Upon extension of the arm, the second motor unwinds the cable, and elastics help the fingers return to the extended position. This addition requires small parts that will maintain the lightweight benefits.

One design that will assist us in our planning is the past student research in UVA Mechanical and Aerospace Engineering Department. The design team in the 2021-2022 academic year developed a similar elbow flexion and extension exoskeleton using a Bowden Cable. The design is effective, but we plan to use a smaller backpack and motor to minimize unused space and weight. The research this team conducted gives us information on the benefits of Bowden Cable actuators, which allows us to move onto advancements in the categories of weight, comfort, and degrees of freedom. The 2022 resulting, "device only weighing 4.1lbs" (Patel, 2023, p. 11), allows for 0.9lbs of additions. While this is likely enough weight to include our hand motions, we anticipate that minimizing other materials will allow us to lower the weight of the existing apparatus.

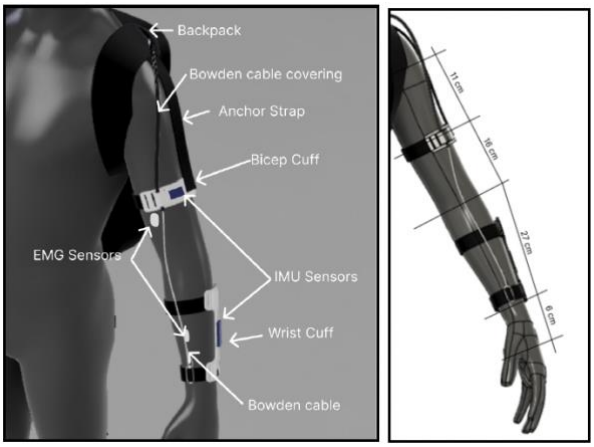

Figure 1: 2022 UVA Mechanical and Aerospace Engineering Department, Upper Limb Soft Exoskeleton Design

We will use kinematic chain calculations to define the required force to lift an average arm and pull in the fingers. These calculations essentially use the geometry, weight, and resistance of the components of the arm, and deliver the required force to lift the arm to a desired angle. Knowing the required forces will allow us to choose efficient motors, hopefully with less mass than the one used by the 2021-2022 academic year's design team. We will also use mannequin testing, followed by trials on team members to ensure safety and smooth continuous motion.

STS Topic

With this research, I will investigate the causes of the disparity in stroke rehabilitation for women and African Americans. It has been established through existing research, "that women are 3.5 times more likely ($p < 0.01$) to be institutionalized six months after stroke than men" (Carmo, et al., 2015, p. 415), showing that gendered differences in stroke recovery lead to a decrease in independence and quality of life. Studies, such as Horner's, referenced in the introduction, have shown that African-American patients face similar setbacks in stroke

recovery. This prior research establishes that the prevalence of post stroke disability is higher for female and African-American patients. The reported effects of lasting disability, such as mental health impacts and institutionalization, must be reduced to better the quality of life in these patient groups.

The cause of rehabilitation disparities lacks sufficient research, though it has been found that, “structural racism creates a level of risk for racial-ethnic minorities that is undermining the health of minority populations” (Magwood, et al., 2019). My research will require evaluating existing literature on the issue and investigating the target patients during the creation of current rehabilitation plans. I will also attempt to speak with doctors who have witnessed the rehabilitation process firsthand. Through these conversations, I hope to establish whether the physical therapy processes used are tailored toward white males.

One group that I hope to interview about the stroke recovery process is the UVA Stroke Center. Through a series of questions, I hope to gain insight on the biological and societal differences that contribute to stroke occurrence and treatment. My design team also plans to speak with physical therapists at Martha Jefferson Hospital to learn about the after-care process. We hope to gather knowledge on the programs and any shortcomings they may have that our exoskeleton could address.

The main difficulty in using literature review in this research is the apparent lack of investigation beyond establishing a disparity. Many studies have been conducted to define how demographics show different recovery patterns, but there is far less published on the cause of recovery variations aside from susceptibility. Using interviews with stroke specialist and physical therapists who have first-hand experience in this field, I hope to help expand on this

research. Through my research I will attempt to answer the question; Why is stroke rehabilitation less effective for females and racial minorities?

As stated in the introduction by Howard (2016), the risk of stroke at 45 is significantly higher in black males than in white males. This risk makes it even more important to address the inequal recovery rates. Some of the hypotheses that I will specifically consider include, less access to treatment for certain demographics, the use of rehabilitation techniques that favor white males, and the lack of accounting for biological differences. Each of these possibilities can be addressed through research or policy changes and could have been acted on years ago. The severity of strokes, and stroke related disability has been concluded from several studies, claiming, "Stroke is the leading cause of long-term disability in western countries" (Carod-Artal, 2009, p. 1).

The anticipated deliverable for this research is a comprehensive understanding of physical rehabilitation for stroke victims. Included in this understanding will be the cause of disparities in recovery rates. The demographics I focus on will be white males, black males, and females, who seem to have the largest gaps in recovery. This information can be applied in physical therapy practices for stroke victims, stroke research centers, and the development of rehabilitation robotics in the future.

Conclusion

The technical portion of this project will produce a two degree of freedom, soft, lightweight, wearable, upper-limb exoskeleton. The design will weigh less than 5 pounds, most of which will be concentrated to a small backpack. The exoskeleton will have a power switch attached to a retractable remote. When the power is on, cables will repeatedly pull up the forearm

and clench the fist, and then return to an open relaxed position. This product will be applicable for rehabilitating the upper limb of stroke patients. The STS portion of this research project will define the causes of varying functional mobility post-stroke between different races and sexes.

The implementation of a wearable exoskeleton for stroke rehabilitation can provide more people with quality care. Based on the results of the STS research, the design can cater towards current disparities, whether they are the result of access to, or quality of, post-stroke rehabilitation.

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